MODELING AND SIMULATION OF MODIFIED SKYHOOK CONTROLLER FOR ACTIVE SUSPENSION SYSTEM

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive.

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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SECOND EXAMINER'S DECLARATION

I hereby declare that I have checked this project report and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

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ABSTRACT

The purpose of this project is to model and simulate the modified skyhook controller for active suspension system a for a quarter car model. There are four parts have been developed in this study namely, the hydraulic actuator model, force tracking controller, quarter car for passive suspension system and modified skyhook for active suspension system. The simulation process of this system was carried out using MATLAB and SIMULINK toolbox. The data for the each parameter were obtained from the research that have done previously. Performance of active suspension system with modified skyhook controller is better than active suspension system with skyhook controller. The simulation results show that the active suspension system could provide significant improvements in the ride quality and road handling compare with the passive suspension system.

ABSTRAK

Tujuan dari projek ini adalah untuk pemodelan dan simulasi pengatur skyhook yang diubahsuai untuk sistem suspensi aktif untuk model suku kereta. Ada empat bahagian untuk dibangunkan dalam kajian ini iaitu, model actuator hidraulik, pengatur penjejak paksaan. Suku kereta untuk sistem suspensi pasif dan skyhook yang diubahsuai untuk sistem suspensi aktif. Simulasi sistem ini akan ditentukan oleh melakukan simulasi komputer dengan menggunakan MATLAB dan aturcara SIMULINK. Data untuk setiap parameter diperolehi dari kajian yang telah dilakukan dahulu. Prestasi sistem suspensi aktif dengan pengatur skyhook yang diubahsuai lebih baik daripada sistem suspensi aktif dengan pengatur skyhook biasa. Keputusan simulasi menunjukkan bahawa sistem suspensi aktif dapat memberikan perbaikan yang signifikan dalam kualiti pemanduan dan pengendalian jalan berbanding dengan sistem suspensi pasif.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Active suspensions systems have been widely studied over the last 30 years, with hundreds of papers published. Most of the published works focus on the outer-loop controller in computation of the desired control force as a function of vehicle states and the road disturbance. It is commonly assumed that the hydraulic actuator is an ideal force generator and able to carry out the commanded force accurately. Simulations of these outer-loop controllers were frequently done without considering actuator dynamics, or with highly simplified hydraulic actuator dynamics.

In real implementation, actuator dynamics can be quite complicated, and the interaction between the actuator and the vehicle suspension cannot be ignored. It is also difficult to produce the actuator force close to the target force without implementing inner-loop or force tracking controller. This is due to the fact that hydraulic actuator exhibits non-linear behavior resulted from servo-valve dynamics, residual structural damping, and the unwanted effects of back-pressure due to the interaction between the hydraulic actuator and vehicle suspension system.

This study focuses on the development of a hydraulic actuator model including its force tracking controller for an active suspension system. Force tracking control of the hydraulic actuator model is then performed using Proportional Integral (PI) controller for a variety of the functions of target forces namely step, sinusoidal, pulse, and repeating functions.

Then, this study continues with implementing the modified skyhook controller of active suspension system to the quarter car of passive suspension system to verify that active suspension system is better than passive suspension system. The performance of active suspension system also can be increase by the skyhook controller that will be discussed on the next chapter.

1.2 PROBLEM STATEMENT

The suspension system that commonly applied on the vehicle is a passive suspension system in which its spring stiffness and dumping value is constant. In the passive suspension system, it damping system has not yet gives a high performance where its vibration amplitude still high and the time required terminating the vibration is quite longer. To overcome this condition, it is then introduced a semi-active suspension and active suspension system. Unfortunately the semi-active systems can only change the viscous damping coefficient of the shock absorber, and do not add energy to the suspension system. So, the active suspension becomes a better choice to keep the quality of the car comfortable on any road condition.

1.3 OBJECTIVE

The objectives of this research are as follows:

a) To develop hydraulic model of the active suspension system
b) To develop force tracking controller for the system
c) To develop a quarter car model using passive suspension system
d) To develop modified skyhook controller for a active quarter car suspension using hydraulic actuator

1.4 SCOPE OF WORK

The scopes of work for this study are as follows:

a) Study on active suspension system for a quarter car model
b) Design the system by using MATLAB/SIMULINK
c) Simulate the system using MATLAB/SIMULINK

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

With a reference from various source such as books, journal, notes, thesis and internet, literature review has been carry out to collect all information related to this project. This chapter discussed about active suspension system for a quarter car model that will be designed and simulated by using software Matlab/Simulink.

2.2 OVERVIEW OF VEHICLE SUSPENSION SYSTEM

Traditionally automotive suspension designs have been a compromise between the three conflicting criteria of road holding, load carrying and passenger comfort. The suspension system must support the vehicle, provide directional control during handling maneuvers and provide effective isolation of passenger or payload from road disturbances. Good ride comfort requires a soft suspension, whereas insensitivity to applied loads requires stiff suspension.

The primary functions of a suspension system are to provide vertical compliance so the wheels can follow the uneven road, isolating the chassis from roughness in the road. It can be maintain the wheels in the proper steer and camber attitudes to the road surface. The suspension also react to the control forces produced by the tires-longitudinal (acceleration and braking) forces, lateral (cornering) forces, braking and driving torques. It can be keep the tires contact with the road with minimal load variations and resist roll of the chassis.

The properties of a suspension important to the dynamics of the vehicle are primarily seen in the kinematic (motion) behavior and its response to the forces and moments that it must transmit from the tire chassis. In addition, other characteristic considered in design process are cost, weight, package space, manufacturability, ease of assembly, and others.

Therefore, each wheel is connected to a system of springs and dampers, which provide flexible but restrained wheel movement. The spring rate or stiffness, damper effects of the shock absorber and the ratio of the sprung mass to the unsprung mass are important parameters, which affect the ride qualities, as discussed earlier.

The following sub sections attempt to present a brief view on the key elements of available vehicle suspension system designs and describe their operating characteristics, ranging from the conventional system to the more advanced systems.

2.2.1 Passive Suspension System

The passive suspension has no means of adding external energy to the system because it contains only passive elements such as damper and a spring. Therefore its rates and forces can't be varied by external signals. When we are using a passive suspension method by choosing a step unit, we will obtain the output in a second order system and would have an overshoot. It depends on the value that has been set. Passive suspension is divided into two parts. They are unsprung and sprung. The purpose is to reduce the wheel loading.

If the passive suspension model is observe it consists of two components. The components are a spring and a damper which are in a parallel position. The value of the spring and damper cannot be changed, as it is a constant. As a conclusion, it is difficult to control the movement of the car because it is impossible to load any controller to the model. The effects of the spring are to impart oscillatory force to the sprung mass with smooth changes in acceleration and velocity.

The amplitude of the motion of the mass depends upon the frequency and magnitude of the wheel motion. In technical form, they are velocity-sensitivity hydraulic damping devices. In other words, the faster they move, the more resistance there is to that movement. They work in conjunction with the spring. The spring allows movement of the wheel to allow the energy in the road shock to be transformed into kinetic energy of the unsprung mass. The force imparted by the wheel to the base of the spring will thus produce an acceleration of the sprung mass. Since this force is also related to the mass and acceleration of the unsprung mass.

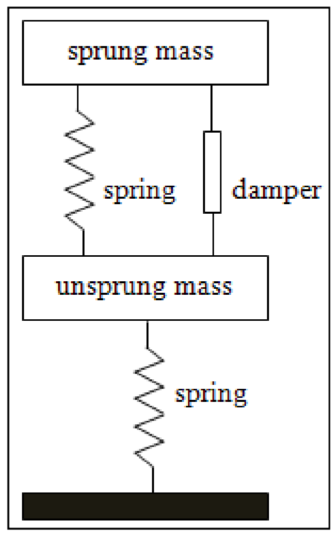

Figure 2.1: Passive suspension system

[Source: Prof. Dr. Yahaya Md. Sam, Robust Control Of Active Suspension System For A Quarter Car Model]

2.2.2 Semi Active Suspension System

As the passive suspension, semi active suspension has no force actuator. It is possible to continuously vary the rate of energy dissipation using a controller damper, but it is impossible to add energy. Semi-active suspension has the same concept with the passive suspension. It still consists of a spring and a damper. The value of the spring and damper cannot be changed, as it is a constant. Any type of controller can be loaded at the damper to control the movement of the car. The damper which has a modified value will be limited to a certain range but it still not able to regulate unless the damper is set to a setting value.

Semi active suspension has the potential to attain more widespread use in mass produced vehicles than fully active system because of their lower cost and their negligible demand for power. An important aspect, in which the performance of ‘semi active’ suspension is not satisfactory, is high frequency harshness that has been observed in road tests and reported in analytical studies of semi active suspension. More important for semi active suspensions the rapid variations of damping coefficients and consequently suspension forces will provide persistent excitation of the structural vibrations.

A good semi active system should provide high damping for low frequency inputs to achieve good body isolation, low damping in the mid -frequency range for good comfort, adequate damping to control the wheel hop, especially under conditions of motion that requires the development of lateral forces and finally increased damping of structural modes. Semi active suspension that use feedback of modal variables reduces structural vibrations in comparison to the corresponding systems with rigid body based controllers. The semi active suspension is shown in Figure 2.2.

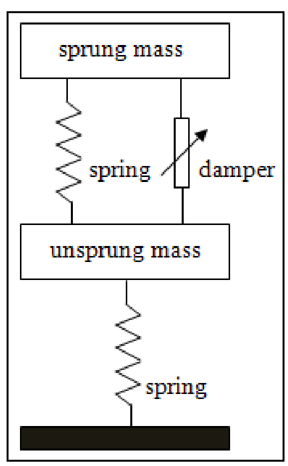

Figure 2.2: Semi Active Suspension System

[Source: Prof. Dr. Yahaya Md. Sam, Robust Control Of Active Suspension System For A Quarter Car Model]

2.2.3 Active Suspension system

The active suspension can supply energy from external source and generate force to achieve the desired performance. The ability to control the energy according to the environment provides the flexibility in control and better performance of suspension system. For this reason, the active suspension is widely investigated. Active suspension model is also similar to a passive suspension model. The difference between the two models is that the damper is replacing with an actuator. The function of the actuator is as a controller to the system and the advantage is that the system can be regulated at anytime.

Active suspensions differ from the conventional passive suspensions in their ability to inject energy into the system, as well as store and dissipate it. Crolla (1988) has divided the active suspensions into two categories; the low-bandwidth or soft active suspension and the high-bandwidth or stiff active suspension. Low bandwidth or soft active suspensions are characterized by an actuator that is in series with a damper and the spring as shown in Figure 2.3. Wheel hop motion is controlled passively by the damper, so that the active function of the suspension can be restricted to body motion. Therefore, such type of suspension can only improve the ride comfort. A high-bandwidth or stiff active suspension is characterized by an actuator placed in parallel with the damper and the spring as illustrated in Figure 2.4. Since the actuator connects the unsprung mass to the body, it can control both the wheel hop motion as well as the body motion. The high-bandwidth active suspension now can improve both the ride comfort and ride handling simultaneously. Therefore, almost all studies on the active suspension system utilized the high-bandwidth type.

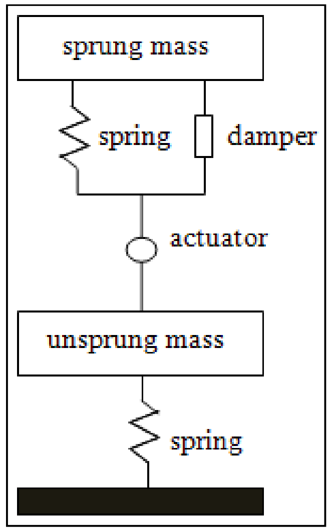

Figure 2.3: A low bandwidth or soft active suspension system

[Source: Prof. Dr. Yahaya Md. Sam, Robust Control Of Active Suspension System For A Quarter Car Model]

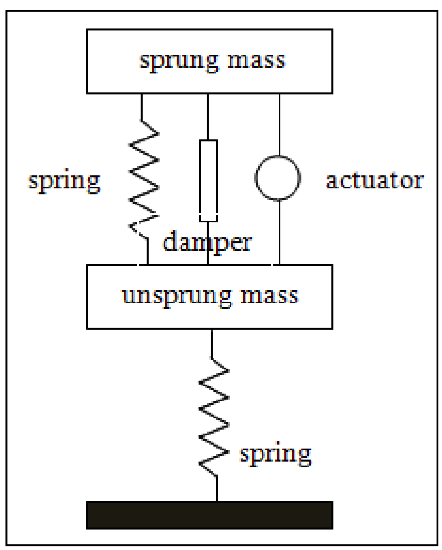

Figure 2.4: A high bandwidth or stiff active suspension system

[Source: Prof. Dr. Yahaya Md. Sam, Robust Control Of Active Suspension System For A Quarter Car Model]

Active suspension can overcome many limitations of passive system and eliminate or at least lessen, the need to compromise among a variety of operating conditions and among the generally conflicting goals of providing good isolation of the body (ride comfort), maintaining uninterrupted contact between the tires and the roads (road holding) and stability the vehicle body (handling).

2.3 CONTROL SYSTEM

A control system is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems.

There are two common classes of control systems, with many variations and combinations: logic or sequential controls, and feedback or linear controls. There is also fuzzy logic, which attempts to combine some of the design simplicity of logic with the utility of linear control. Some devices or systems are inherently not controllable.

The term "control system" may be applied to the essentially manual controls that allow an operator to, for example, close and open a hydraulic press, where the logic requires that it cannot be moved unless safety guards are in place.

An automatic sequential control system may trigger a series of mechanical actuators in the correct sequence to perform a task. For example various electric and pneumatic transducers may fold and glue a cardboard box, fill it with product and then seal it in an automatic packaging machine.

In the case of linear feedback systems, a control loop, including sensors, control algorithms and actuators, is arranged in such a fashion as to try to regulate a variable at a set point or reference value. An example of this may increase the fuel supply to a furnace when a measured temperature drops. Proportional Integral Derivative (PID) controllers are common and effective in cases such as this. Control systems that include some sensing of the results they are trying to achieve are making use of feedback and so can, to some extent, adapt to varying circumstances. Open-loop control systems do not directly make use of feedback, but run only in pre-arranged ways.

2.3.1 Proportional –Integral –Derivative (PID) Controller

The PID family controller (P, PD, PI, and PID) are widely used and successfully applied to many applications, for many years. The facts of their successful application, good performance, easiness of tuning are speaking for themselves and are sufficient rational for their use.

As well known PID control has been one of the most popular control methods for practical processes from 1940s when Ziegler and Nichols produced the parameter setting. This tuning method of PID control is to make a desired transient response and steady state by turning the three parameters (Proportional P, Integral I, and Derivative D) with scarce information about the controlled object. In 1960s the method of modern control theory was produced and if we comprehend control object accurately, we can modify the characteristic of control systems using the observed state, that is, we can design the control systems perfectly when it has controllability and observability.

However, in PID control strategy these structural properties were not be prescribed accurately in spite of having used the terminology about the controllability which is now popular term in modern control theory. For this reason, the PID control is seemed to be somewhat indistinct though having some advantages. However control equipment based on the structure of PID control has been practically implemented all over control equipment.

The operation of PID control is basically to control the process by using manipulated magnitude proportional to control error. Generally summing the integral value and the derivative one of the control error to it, we built the manipulated variable of PID control. Considering the time dependence of control error through the integral and derivative operation, the control error dynamically influences to the manipulated variable. Therefore PID control has an effective property indicating a physical relation between the control error and the manipulated variable. The transfer function of a PID controller is given as follows:

$$G_{PID} = K_P\,(1 + \frac{1}{T_i s} + T_d s) \qquad [1]$$

where T_i=K_p/K_i, T_d=K_d/K_p and K_p, K_i and K_d are proportional, integral and derivative gain respectively.

2.3.2 Force Tracking Control of Hydraulic Actuator Model

The structure of force tracking control of hydraulic actuator is shown in Figure 2.5. The hydraulic actuator model take two input namely spool valve position and real time piston speed. Proportional Integral control is implemented which takes force tracking error as the input and delivers control current to drive the spool valve. The target force is represented by step, sinusoidal, pulse and repeating functions.

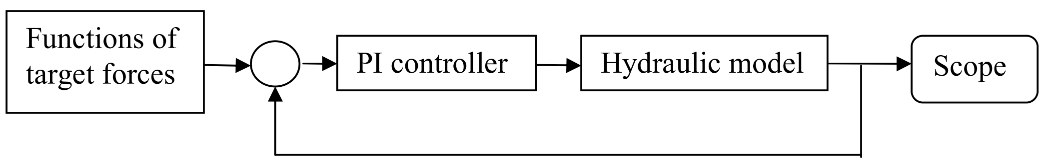

Figure 2.5: Force tracking control of hydraulic actuator

2.4 HYDRAULIC ACTUATOR MODEL

A complete set of a hydraulic actuator consists of five main components namely electro hydraulic powered spool valve, piston-cylinder, hydraulic pump, reservoir and piping system as shown in Figure 2.6. Power supply is needed to drive the hydraulic pump through AC motor and to control the spool valve position. The spool valve position will control the fluid to come-in or come-out to the piston-cylinder which determines the amount of force produced by the hydraulic actuator.

The hydraulic actuators are governed by electro hydraulic servo valve allowing for the generation of forces between the sprung and unsprung masses. The electro hydraulic system consists of an actuator, a primary power spool valve and a secondary bypass valve.